(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 February 2001 (22.02.2001)

PCT

(10) International Publication Number
WO 01/13479 A1

(51) International Patent Classification[7]: H01S 5/06, G02F 1/015, H01S 5/22, 5/026

(21) International Application Number: PCT/SE00/01547

(22) International Filing Date: 4 August 2000 (04.08.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9902916-7 16 August 1999 (16.08.1999) SE

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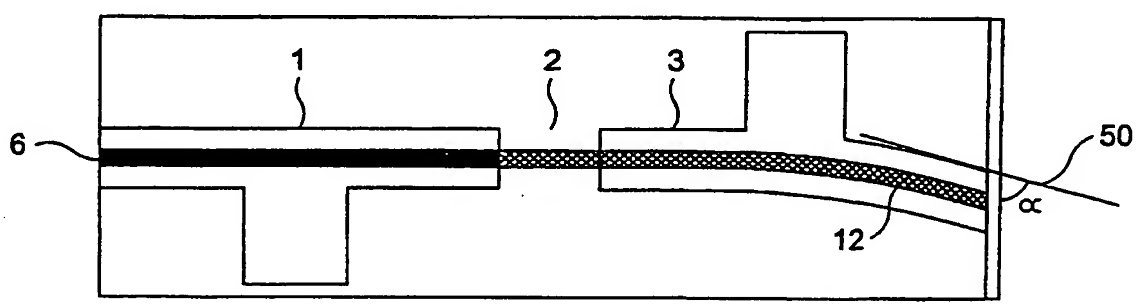
(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*
— *Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: MODULATOR AND INTEGRATED CIRCUIT



(57) Abstract: The present invention relates to a modulator (3) comprised of semiconductor material and intended for modulating a light signal. The modulator includes at least one first cover layer (5) made of semiconductor material and having a first refractive index, a waveguide disposed on said first cover layer and comprised of semiconductor material that has a second refractive index, a second cover layer (10) disposed on said waveguide (12) and comprised of semiconductor material that has a third refractive index. The first and the third refractive indexes in said first and said second cover layers (5, 10) are lower than the second refractive index in said waveguide (12). The first and the second cover layers (5, 10) are connected to a first and a second metal layer (17, 13), where the first metal layer (17) is connected directly or indirectly to the first cover layer (5) and forms a first electric contact surface, and where the second metal layer (13) is connected directly or indirectly to the second cover layer (10) and forms a second electric contact surface. The waveguide (12) is curved or angled such that a tangent (50) to the waveguide (12) at one end surface of the waveguide (12) will meet an end surface of the modulator at an angle (α) other than 90°, such as to reduce reflection of light back through the modulator (3).

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MODULATOR AND INTEGRATED CIRCUIT

FIELD OF INVENTION

The present invention relates to a modulator according to the preamble of Claim 1 and to an integrated circuit according to the preamble of Claim 9.

DESCRIPTION OF THE BACKGROUND ART

Fibre-optic communications links are becoming more and more usual, because of their ability to permit information to be transmitted at high speeds over long distances.

Semiconductor lasers are being used to an increasing extent as signal sources in such fibre-optic systems. There is desired a laser that has a narrow spectral line width and which will enable information to be transmitted at high speeds (bit rates) over long distances without the light pulses of the signal flowing together as a result of dispersion.

The light pulses can be obtained by direct modulation of the laser drive current, in other words with amplitude modulation. An undesired secondary effect of such amplitude modulation resides in unavoidable weak frequency modulation, in other words modulation of the frequency of the light transmitted from the laser. Such a change in wavelength is called chirp. Because of the dispersion of the optical fibre, the spectrally broadened light pulse will undergo pulse dispersion in the time domain as the pulse propagates along the fibre. This problem is exacerbated at increased bit rates and with longer transmission distances.

Chirp can be avoided or at least reduced, by using external modulation. External modulation can be effected with a

separate modulator component or with an integrated modulator component.

For example, an electroabsorption modulator can be integrated on the same substrate as a laser. An electroabsorption modulator can utilise the Franz-Keldshe effect or the Stark effect, in other words an absorption edge of a semiconductor is displaced towards longer wavelengths when an electric field is applied to the semiconductor. When modulating a reverse voltage across the modulator, the absorption edge is modulated and therewith also the amplitude of the transmitted light. It is therefore unnecessary to modulate the laser, wherewith chirp is reduced.

The separate or integrated modulator will preferably be protected against reflections from the end surface of the modulator, particularly in the case of the integrated modulator. If light is reflected back into the laser from the output end of the modulator, the laser will swing in wavelength. It is of great importance to reduce reflections into the laser at high bit rates and/or in the case of long transmission paths. This has been achieved hitherto by treating the component surfaces with an antireflection substance, for instance with a thin layer of SiOx which has a reflective capacity of less than 0.1%.

One problem with this antireflection layer is that it cannot be easily applied to the end surface of the modulator.

DISCLOSURE OF THE INVENTION

The present invention addresses the aforesaid problem with the aid of a modulator according to Claim 1 and with the aid of an integrated circuit according to Claim 9.

The object of the present invention is to provide a modulator with which at least the aforesaid problems are reduced.

One advantage afforded by the present invention is that the precision of the antireflection layer process need not be 100% in order to achieve a comparatively high performance.

Another advantage afforded by the present invention is that its implementation does not require any additional process step.

The invention will now be described in more detail with reference to preferred embodiments thereof and also with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates from above an integrated circuit that includes a modulator according to the invention and a laser.

Figure 2 is a cross-sectional view taken from one side in the longitudinal direction of a waveguide in the modulator and the laser in Figure 1.

Figure 3 is a cross-sectional view of the laser section in the integrated circuit according to Figure 1.

Figure 4 is a cross-sectional view of the insulation section in the integrated circuit according to Figure 1.

Figure 5 is a cross-sectional view of the modulator section in the integrated circuit according to Figure 1.

DESCRIPTION OF PREFERRED EMBODIMENTS

Figures 1 and 2 show an integrated circuit that includes a modulator section 3 according to the invention together with a laser section 1 on a common substrate 4. The modulator section according to the invention may alternatively be disposed on a separate substrate. In the illustrated case, the substrate 4 is an n-doped InP substrate. The laser section is a DFB type section (Distributed Feed Back). An installation section 2 is arranged between the laser section 1 and the modulator section 3. A common metal cathode 17 is provided on the underside of the integrated circuit for soldering purposes. Separate metal anodes for the laser section 13, 14 and the modulator section 15, 16 are provided on the upper side of the integrated component for establishing electric contact with, e.g., bonding wire. Active laser sections and modulator sections can be produced sequentially or simultaneously with selective epitaxial growth or SAG; (Selective Area Growth).

The laser section 1 includes a lower cover layer 5 of n-doped InP, an active layer (waveguide) 6 of GaInAsP having a bandgap wavelength of approximately 1.5 µm, a spacing layer 7 of p-doped InP, a grating layer 8 comprised of a periodically corrugated structure with alternating p-doped InP and p-doped GaInAsP having a bandgap wavelength of about 1.3 µm, an upper cover layer 10 of p-doped InP, and an electric contact layer 11 of p-doped InGaAs. A metal electric contact layer 13 and a bond metal layer 14 are disposed on said electric contact layer. As shown in Figures 3, 4 and 5, an etched ridge 10 is surrounded by an insulator 19 comprised, e.g., of benzocyclobutene (BCB). The active layer 6 may comprise an MQW structure (Multiple Quantum Well) with stretched or extended layers. The active layer 6 may be surrounded by an SCH (Separate Confinement Heterostructure) layer of InGaAsP having a bandgap wavelength of approximately 1.3 µm. The grating layer 8 may include one or more phase shifts. The structure also includes a thin etched stop layer 9.

The insulation section 2 includes a lower cover layer 5 of n-doped InP, an active layer (waveguide) 12 of GaInAsP whose bandgap wavelength is approximately 0.06 µm smaller than the bandgap wavelength of the active layer 6, an upper cover layer 10 of p-doped InP, an electric contact layer 11 of p-doped InGaAs. A layer of GaInAsP having an intermediate bandgap wavelength of about 1.1 µm may be arranged between the active layer 12 and the upper cover layer 10. Ion implantation for insulation is carried out in at least the upper cover layer 10. The upper cover layer is surrounded by an insulator comprised, for instance, of benzocyclobutene (BCB), said cover layer having the form of an etched ridge in the illustrated case. Alternatively, the active layer 12 may comprise an MQW structure with stretched or extended layers.

In its simplest form, the modulator section may be a reverse biased PN junction. A lower cover layer may, e.g., be comprised of an n-doped InP layer, an active layer (waveguide layer) may, e.g., be comprised of an essentially non-doped InGaAsP layer, and an upper cover layer may, e.g., be comprised of a p-doped InP layer. The upper and the lower cover layers are preferably provided with metallic electric contact layers.

The modulator section 3 in Figures 2 and 5 includes a lower cover layer of n-doped InP, an active layer (waveguide) 12 of GaInAsP whose bandgap wavelength is approximately 1-06 µm smaller than the bandgap wavelength of the active layer 6, an upper cover layer 10 of p-doped InP, and an electric contact layer 11 of p-doped InGaAs. A metal contact layer 15 and a metal bonding layer 16 are provided on the contact layer 11. A layer of GaInAsP having an intermediate bandgap wavelength of approximately 1.1 µm may be provided between the active modulator layer 12 and the upper cover layer 10. The upper

cover layer is surrounded by an insulator 19 comprised for instance of benzocyclobutene (BCB), said upper cover layer having the form of an etched ridge in the illustrated case; see Figures 3, 4 and 5. In the case of the illustrated embodiment, an antireflection layer 20 is provided on the end surface of the section. The aforesaid active layer 12 may alternatively comprise an MQW-structure with stretched or extended layers.

Ions may be implanted on both sides of the ridge-shaped upper cover layer 10 of the modulator section 3; see Figures 3, 4 and 5. Such lateral insulation may be in self-alignment with the upper metallization 16 of the modulator.
The refractive index of the active layer in the laser section, the insulation section and the modulator section are higher than the refractive index of the surrounding layers. The surrounding layers in the modulator, the insulation section and the laser section have a bandgap which is greater than the bandgap of the active layer so as to avoid absorption of the light signal in said layers.

The aforedescribed integrated circuit can be manufactured by growing the lower cover layer 5, the active layer 6, the spacing layer 7 and the grating layer 8 on an InP substrate. The substrate is coated with an etching and re-growing mask comprised of SiNx for instance, and thereafter selectively etching the active layer 6, the spacing layer 7 and the grating layer 8 away from that surface or those surfaces that are not the laser section or shall belong to the laser section. The active modulator layer 12 and a thin covering layer of InP are then regrown. After having removed the SiNx mask, the DFB grating is etched in the layer 8, whereafter the upper cover layer 10, the etched stop layer 9 and the contact layer 11 are grown. A waveguide ridge structure is etched in the contact layer 11 and the upper cover layer 10. The electrode metallization 13, 15 extends along the full

length of the component and functions as a self-aligned etching mask. The side walls of the cover layer are not under-etched when the ridge is orientated in the [011]-direction of the crystal and etching is effected with a suitable etching process, e.g. with an hydrochloric acid based (HCl) wet etching process. The etched depth is restricted by the stop layer 9.

The electrode metallization and the electric contact layer are then removed from that apart of the ridge which lies within the insulation section. The upper cover layer 10 in the insulation section is implanted with hydrogen ions (H+) or with some other ion, to enhance the insulation between the electrodes 13, 15. The structure can be made planar, by depositing an insulating layer 19. The bonding metallization 14, 16 is then deposited.

The modulator section 3 is curved or angled so that it will meet the end surface of the integrated circuit at an angle other than a right angle. This angle, which is not a right angle, may be such as to cause the waveguide at said end surface to deviate from the crystal [011] direction by about 7° when the remaining non-curved or angled part of the waveguide is disposed parallel with said crystal direction. Angling of the waveguide in relation to the end surface of said circuit enables back-reflections into the modulator to be reduced to an acceptable level.

The back reflections from the end surface of the modulator can be reduced still further, by applying an antireflection layer to the end surface of the waveguide in said modulator.

The active layers 6, 12 may, alternatively, be grown at the same time as SAG.

The DFB laser 1 is powered with direct current via the electrode 13, 14. The light emitted is guided into the layer 12. The light is absorbed in the layer 12 in the modulator 3 as a result of applying a reverse voltage to the electrode 15, 16. The electrodes 13, 14 and 15, 16 are insulated electrically from one another by the insulation section 2. The upper cover layer 10 in the insulation section 2 provides adequate insulation between the electrodes by virtue of its resistance being increased with said ion implantation 18.

It is preferred that a modulator can be driven at high signal frequencies, Gbit/s. So-called band-bending occurs at the abrupt transition between p-InP and InGaAsP, such that holes are accumulated at said transition, such accumulation being referred to as hole pile up. This accumulation, or pile up, is dependent on the magnitude of the reverse voltage that has been applied across the modulator. In modulation, these holes will form a charge density or volume that varies over a modulation cycle. This corresponds to a capacitive load that can impair or degrade the properties of the component at high signal frequencies.

This abrupt transition between p-InP and InGaAsP can be smoothed out by providing between the active layer 12 and the upper cover layer 10 a layer of GaInAsP that has the intermediate bandgap wavelength of about 1.1 µm. The object of this layer is to increase the modulation bandwidth, by reducing hole pile up. The filling 19 makes the component planar and provides mechanical protection. The filling 19 also raises the metallization on the upper side 14 and 16 of the component, thereby reducing the capacitance in the modulator. One advantage in this respect is that it enables the modulator section 3 to be modulated at a high frequency. The high frequency properties may also be improved by a lateral electrical limitation, which can be achieved with insulation on both sides of the modulator ridge.

The aforedescribed modulator is constructed in accordance with RWG (Ridge Waveguide Structure). The present invention may, of course, also be applied with modulators and integrated circuits including a modulator and a laser constructed in accordance with BH (Buried Heterostructure). A combination of a laser constructed according to RWG and a modulator according to BH, and vice versa, is feasible.

The laser 1 in the integrated circuit may be a semiconductor laser of the DFB type (Distributed Feed Back) or of the DBR type (Distributed Bragg Reflecting), for instance.

According to the invention, the modulator 3 may be of an electroabsorption type or of the Mach-Zehnder type. Stark effect or Franz-Keldysh effect can be utilised when the modulator 3 is of the electronabsorption type.

In the case of the aforedescribed and illustrated embodiment, the polarity is such that the anode is connected to the upper cover layer 10 and the cathode to the lower cover layer 5. Naturally, the polarity is shifted if the lower cover layer 5 is a p-doped Inp layer and the upper cover layer 10 is an n-doped InP layer.

It will be understood that the invention is not restricted to the aforedescribed and illustrated embodiments thereof and the modifications can be made within the scope of the following Claims.

CLAIMS

1. A modulator (3) comprised of semiconductor material and intended for modulating a light signal, said modulator including at least one first cover layer (5) comprised of semiconductor material and having a first refraction index, a waveguide (12) disposed on said first cover layer (5) and comprised of a semiconductor material that has a second refractive index, and a second cover layer (10) disposed on said waveguide (12) and comprised of semiconductor material that has a third refractive index, wherein the first and third refractive indexes in said first and second cover layers (5, 10) are lower than said second refractive index in said waveguide (12), and wherein the first and the second cover layer (5, 10) are connected to a first and a second metal layer (17, 13), wherein the first metal layer (17) is connected directly or indirectly to the first cover layer (5) and forms a first electric contact surface, and wherein the second metal layer (13) is connected directly or indirectly to the second cover layer (10) and forms a second electric contact surface, **characterised** in that the waveguide (12) is curved or angled so that a tangent (50) to the waveguide at one end surface of said waveguide (12) meets an end surface of the modulator at an angle (α) other than 90° such as to reduce reflection of light back through the modulator (3).

2. A modulator (3) according to Claim 1, **characterised** in that a tangent to a part of the waveguide (12) before the curved or angled part is parallel with a [011] direction in the semiconductor material.

3. A modulator (3) according to Claim 1 or 2, **characterised** in that the modulator includes an antireflection layer (20) on one end surface of the waveguide (12).

4. A modulator (3) according to any one of Claims 1-3, **characterised** in that the modulator is of the electronabsorption type.

5. A modulator (3) according to Claim 4, **characterised** in that the modulator utilises the Stark effect.

6. A modulator (3) according to Claim 4, **characterised** in that the modulator utilises the Franz-Keldysh effect.

7. A modulator according to any one of the preceding Claims, **characterised** in that the waveguide is of the buried heterostructure type.

8. A modulator (3) according to any one of Claims 1-4, **characterised** in that the waveguide is a ridge waveguide structure.

9. An integrated circuit on a semiconductor substrate, comprising at least one laser (1) and a modulator (3) which are optically connected together, **characterised** in that the modulator (3) is the modulator according to any one of the preceding Claims.

10. An integrated circuit according to Claim 9, **characterised** by an ion-implanted insulation region (2) between said laser (1) and said modulator (3).

11. An integrated circuit according to Claim 9 or 10, **characterised** in that the laser (1) is of the DFB type (Distributed Feed Back).

12. An integrated circuit according to Claim 9 or 10, **characterised** in that the laser (1) is of the DBR type (Distributed Bragg Reflection).

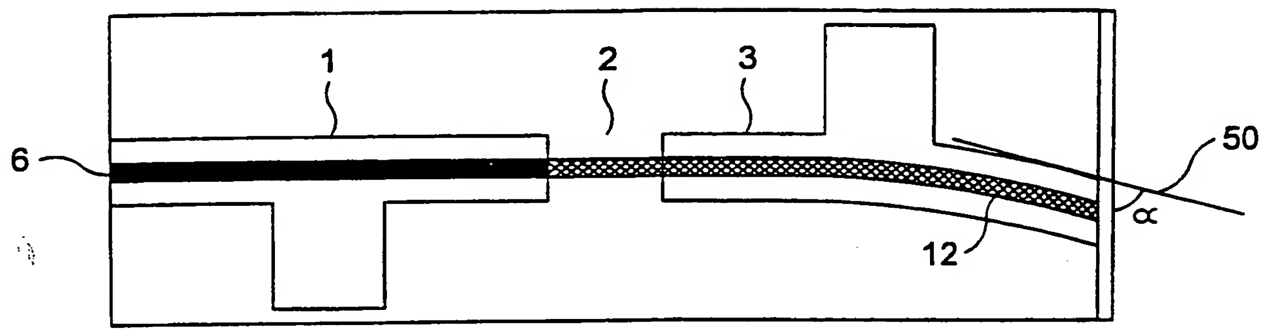

Fig. 1

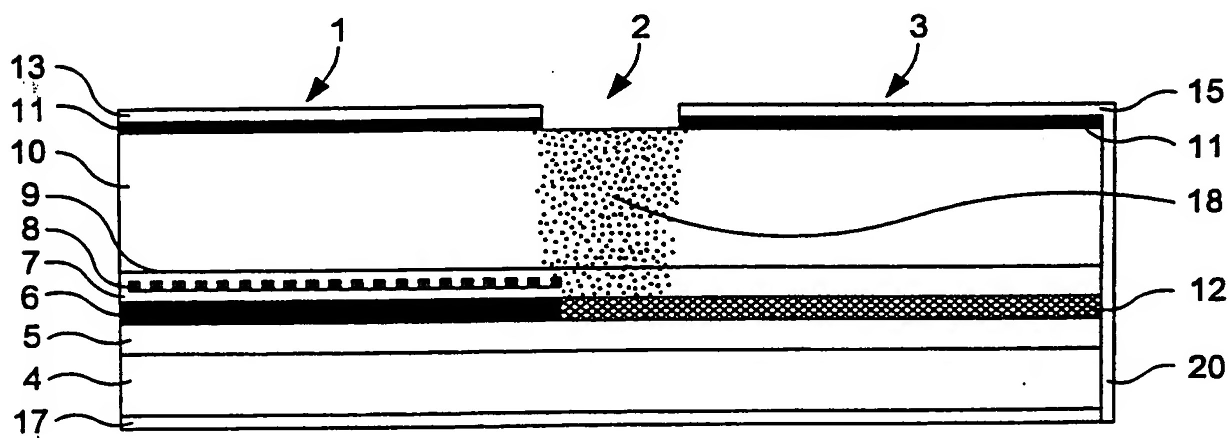

Fig. 2

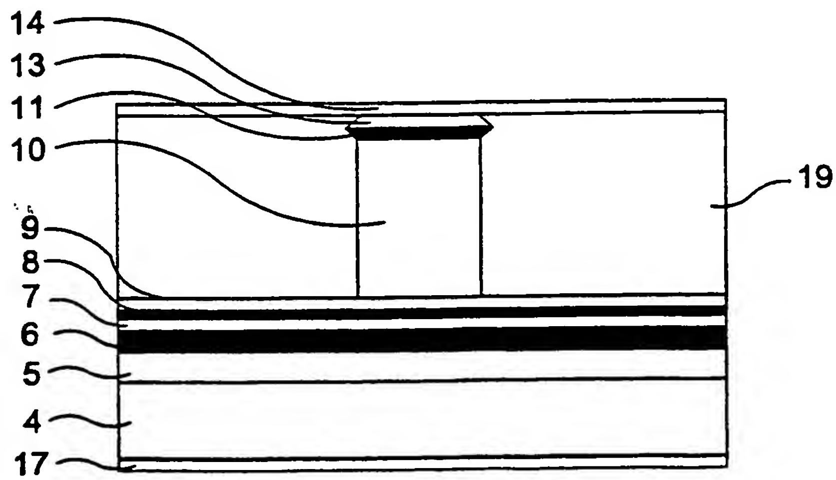

Fig. 3

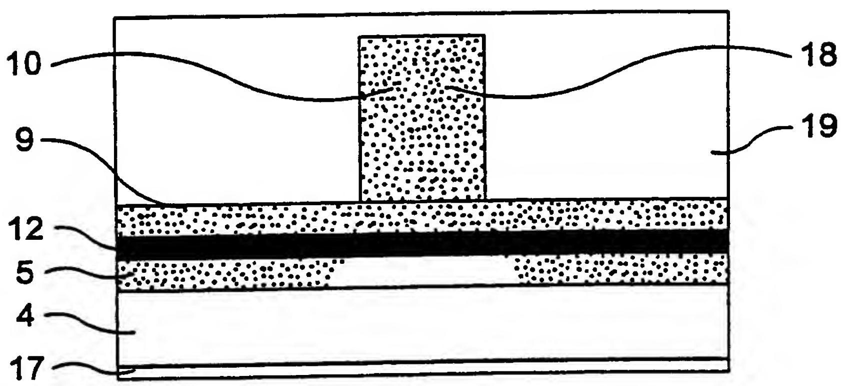

Fig. 4

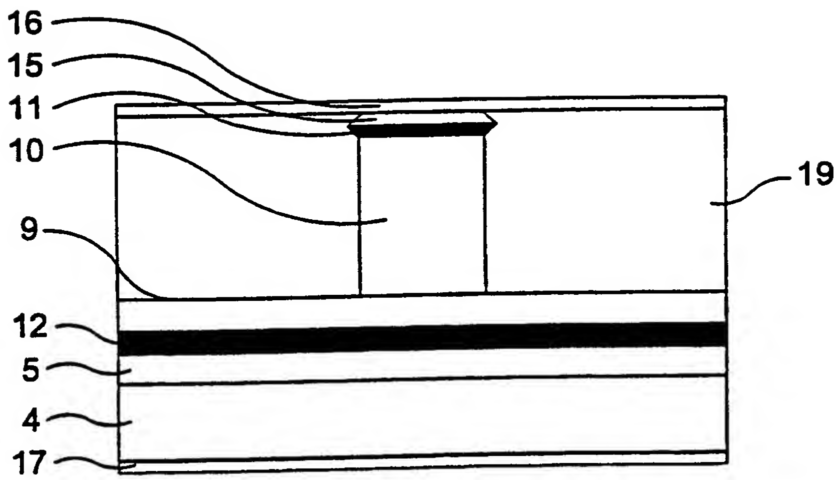

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01547

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H01S 5/06, G02F 1/015, H01S 5/22, H01S 5/026
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H01S, H01L, G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP 0653822 A1 (AT&T CORP.), 17 May 1995 (17.05.95), column 3, line 40 - column 4, line 10	1-12
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X	EP 0637111 A1 (NEC CORPORATION), 1 February 1995 (01.02.95), column 10, line 11 - column 11, line 54	1
Y		2-12
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 December 2000	22 -12- 2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Fredrik Wahlin/MN Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01547

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	A wavelength-tunable curved waveguide DFB laser with an integrated modulator Hsu,A.; Chuang, et al. Quantum Electronics, IEEE Journal of Volume: 35 Issue: 6, June 1999 Pages: 961-969 -- --------	13

INTERNATIONAL SEARCH REPORT
Information on patent family members

04/12/00

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